The Grid of the Future

Power system planning and operation for the integration of new solutions and technologies supporting the massive integration of renewable energy resources.

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Workshop in PV, grid and grid integration
University Cyprus, Lefkosia, 13th December 2016

Content

1. DER System Integration in Austria
2. Related Technologies, Experiences and Results
   - PV Inverter Integration
   - Voltage Control in Distribution Networks
   - Storage and Load Flexibility Integration
3. Technology Development and Validation Approaches
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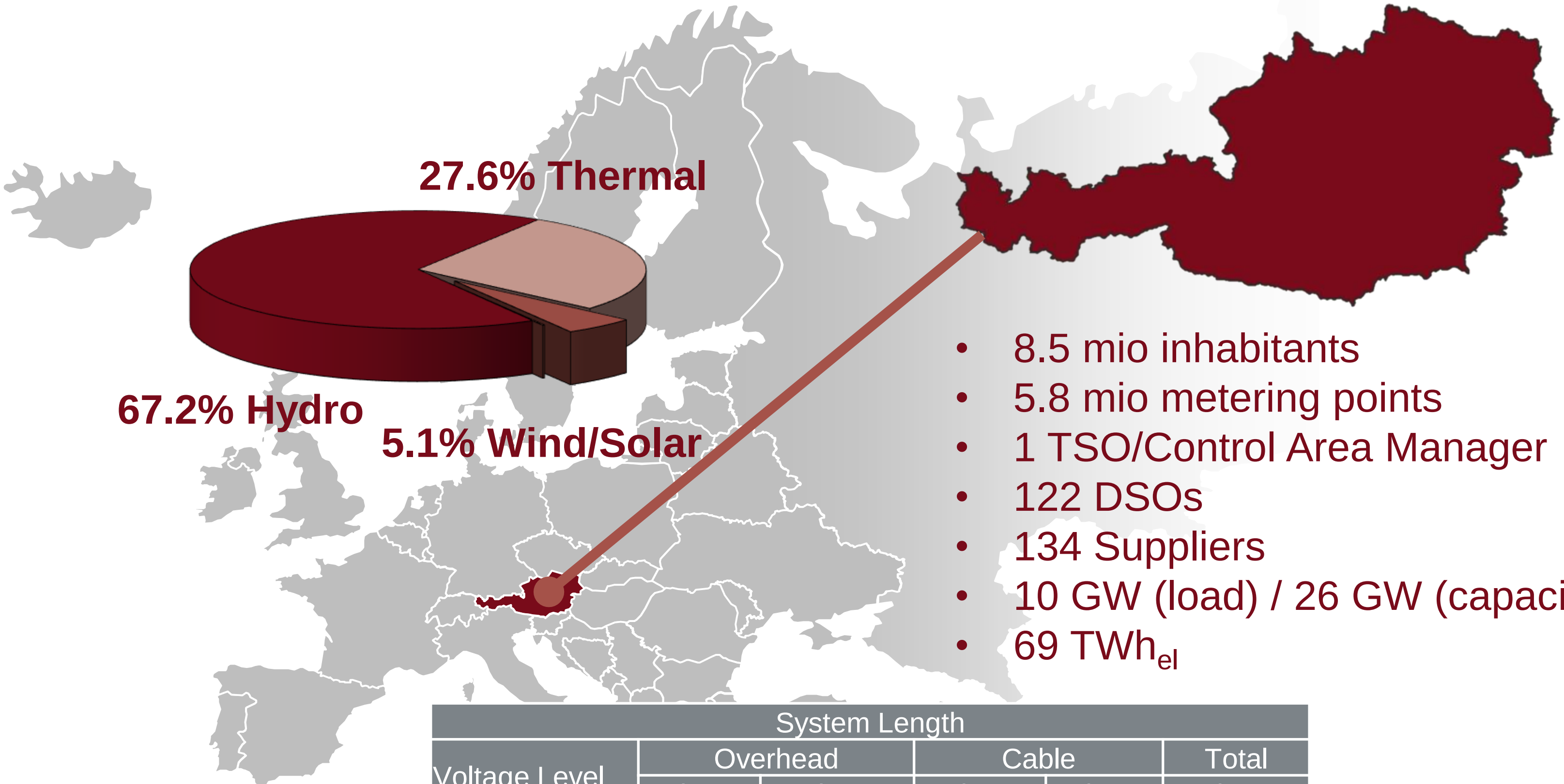
Austria – Facts and Figures

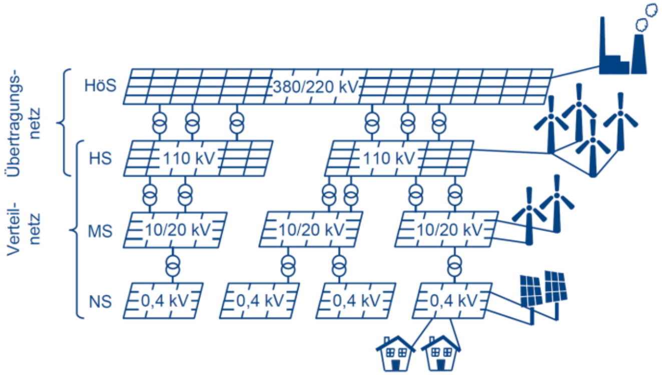


- 8.5 mio inhabitants
- 5.8 mio metering points
- 1 TSO/Control Area Manager
- 122 DSOs
- 134 Suppliers
- 10 GW (load) / 26 GW (capacity)
- 69 TWh_{el}

System Length					
Voltage Level	Overhead		Cable		Total
	km	Share	km	Share	km
380 kV	2.989	1,2%	55	0,0%	3.043
220 kV	3.682	1,4%	5	0,0%	3.686
110 kV	10.498	4,1%	767	0,3%	11.266
1kV < 110 kV	27.538	10,7%	41.165	16,0%	68.703
<1 kV	35.309	13,7%	135.461	52,6%	170.770
Total	80.015	31,1%	177.453	68,9%	257.468

Austria - Facts and Figures

- The distribution network in Austria typically is designed with three voltage levels:
  - High voltage 110 kV
  - Medium voltage: 10 kV, 20 kV, 30 kV
  - Low voltage: 0.4 kV



- Main challenge in Austria is the massive integration of renewable-based distributed generation in particular into the distribution system level in mainly rural areas.

Renewables integration

- **Distributed Energy Resources (DER) ➡ the shift from from troublemaker to troubleshooter**

disconnection in case of

- **faults**
- **over- and under frequency**
- **over- and under voltage**

resulted in “problems” - e.g. 50.2 Hz problem

~~**„fit and forget“**~~

~~no active role of DER~~

„network services by DER“

Integration means to take over network services

➡ RES have to support grid operation

- **Fault ride through (FRT)**
- **Frequency control**
- **Local voltage support**

Solutions related to network planning and operation

- Scalability and replicability of smart grids solutions for enhanced hosting capacity (for e.g. PV/EV):
  - How much reserve is available?
  - What to deploy?
  - Where to deploy and where to start?
- Improvement of network planning methods using available measurement data
- Optimisation of network operation (e.g. open tie point optimisation, network reconfiguration for loss minimisation)
- Seamless data management between network planning and operation
- Enhanced observability for MV/LV networks
- Interaction between voltage levels HV/MV/LV networks and system issues

Smart Grids @ AIT

Planning and Operation

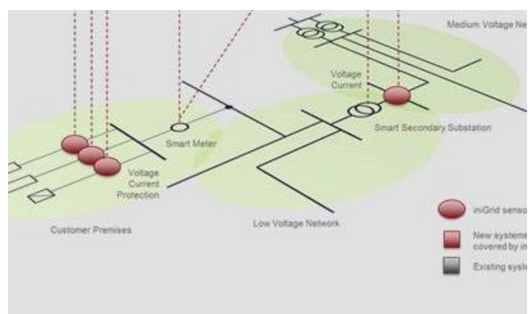
- Integration of Distributed Generation, Flexibility, E-Mobility, etc
- Interaction transmission and distribution system
- Interactions electricity and thermal grids

ICT and Controls

- Robust & scalable control architectures
- Information & communication technologies for monitoring & automation
- Advanced metering infrastructure

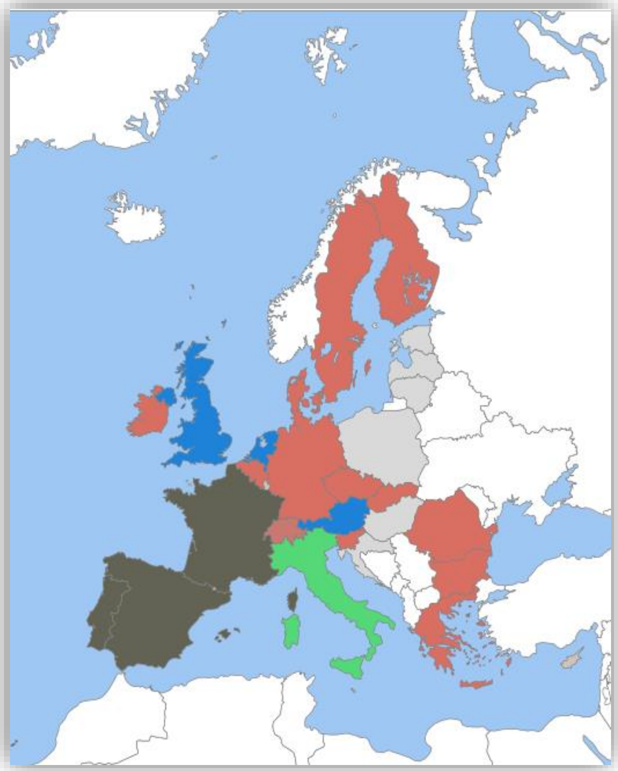
Power Electronics & System Components

- Power electronic converters for grid-connected systems
- High current applications & insulation systems
- Grid codes & interconnection requirements



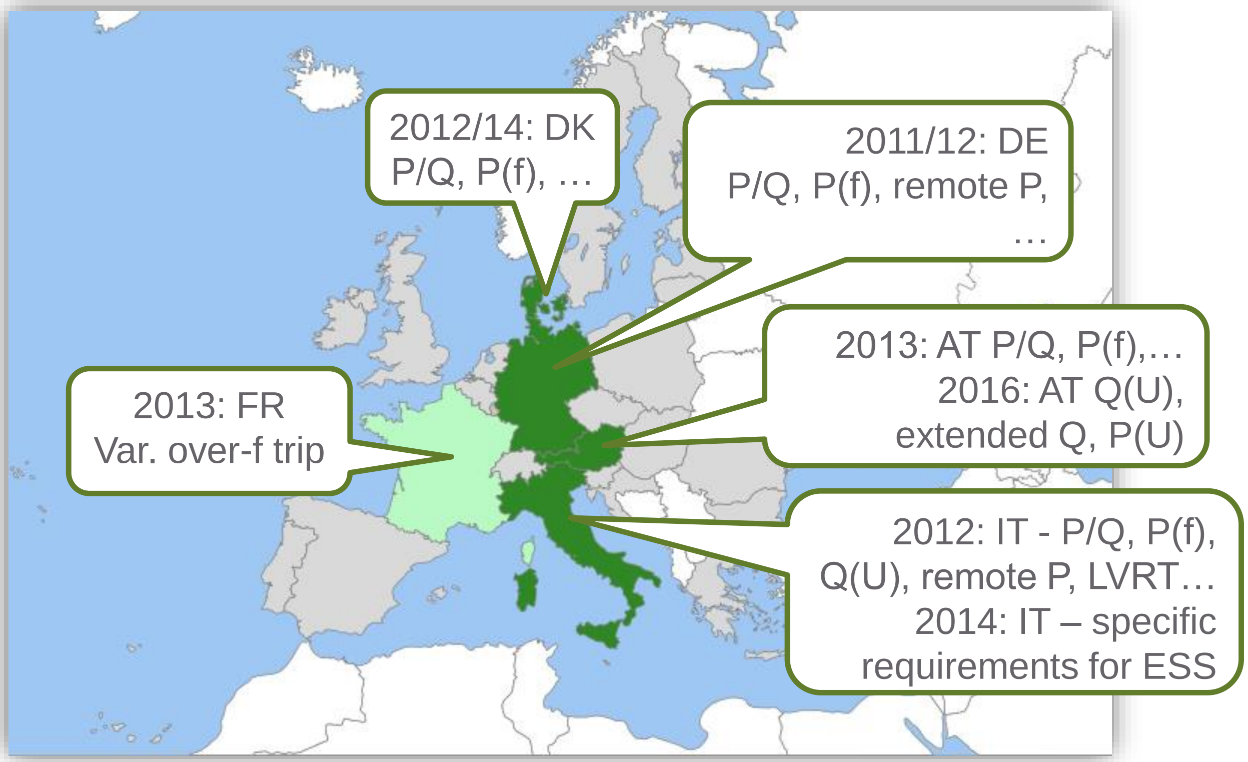
Example 1: PV Inverter Integration

Framework for DER interconnection in Europe
Country specific grid codes and standards



- As of today there is still no formal EU wide directive on DER grid interconnection
- Country specific grid codes, standards, guidelines, laws
  - Different legal and administrative levels
  - Fundamental differences between the countries
- Issues for manufacturers and project developers
  - Specific product settings for each country/market
  - Complex and time consuming certification schemes
  - Increased costs and reduced competiveness
- Critical issues for power system operation
  - Lack of coordination and compatibility
  - Risk of losing system security during wide-scale events due to undefined behaviour of DER (example 50.2 Hz issue)

Requirements for advanced grid support in Europe: DR connected to LV



Selected European Country Requirements – LV Connection

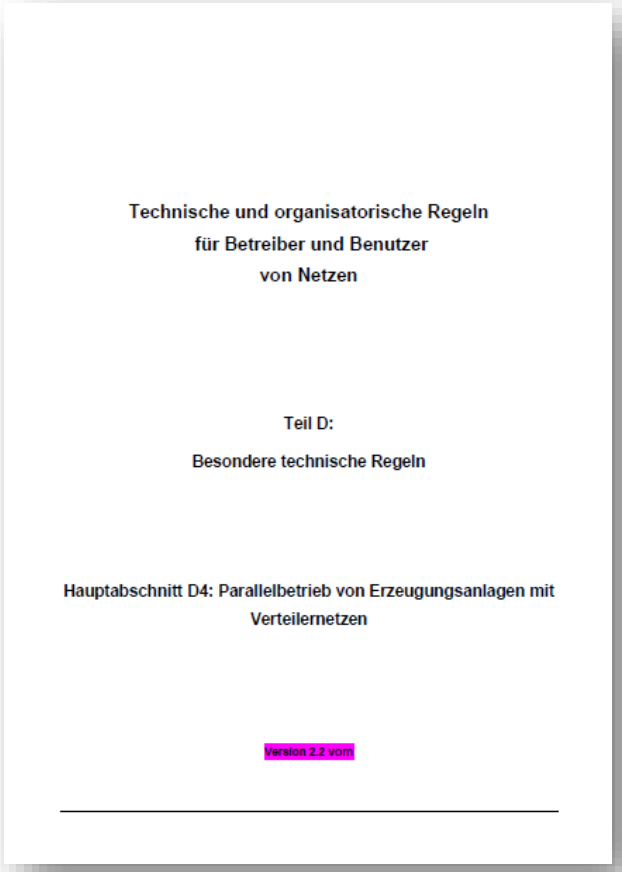
Country	Europe (≤16 A)	Germany	Italy	Austria	France	Spain	Europe (≤16 A)	Europe (>16 A)
Function	2007	2011	2014	2016	2013	11/14	2013	2014
P at low f	No	Yes (all)	Yes (all)	Yes	No	No	Yes	Yes
P(f)	No	Yes (all)	Yes (all)	Yes	Yes*	No	Yes	Yes
Q/cosφ	No	>3.68kVA	>3 kVA	>3.68kVA	No	No	Yes	Yes
Q(U)	No	No	>6 kVA	Yes*	[illegible]	[illegible]	[illegible]	Yes
P(U)	No	No	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Remote P	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	No	No	Yes
Rem. trip	[illegible]	[illegible]	[illegible]	No	No	No	No	Yes
LVRT	[illegible]	No	>6 kVA	No	No	No	No	Yes
HVRT	No	N/A	No	No	No	No	No	Yes
Reference	EN 50438 2007 (superseded by EN 50438 2013)	VDE AR N 4105: 2011	CEI 0-21:2014	TOR D4:2016	* ERDF-NOI-RES_13E Version 5 - 30/06/2013	RD 1699/2011 206007-1 IN:2013	EN 50438 2013	CLC/TS 50549-1:2015

Standards are under continous revision and have to keep track with the technical as well as with the market development

Austrian Grid Code for DER interconnection 2016

- TOR D4
  - Technical and organisational rules for operators and users of grids, Parallel operation of generating plants with distribution grids

- Developed by the Austrian Authority for Electricity Market in a partly open discussion process
- Status: Part of „market rules" which are an integral component of all contracts between grid operators and users (customers)



Technische und organisatorische Regeln
für Betreiber und Benutzer
von Netzen

Teil D:
Besondere technische Regeln

Hauptabschnitt D4: Parallelbetrieb von Erzeugungsanlagen mit Verteilernetzen

Version 2.2 vom

Regulatory framework recently revised

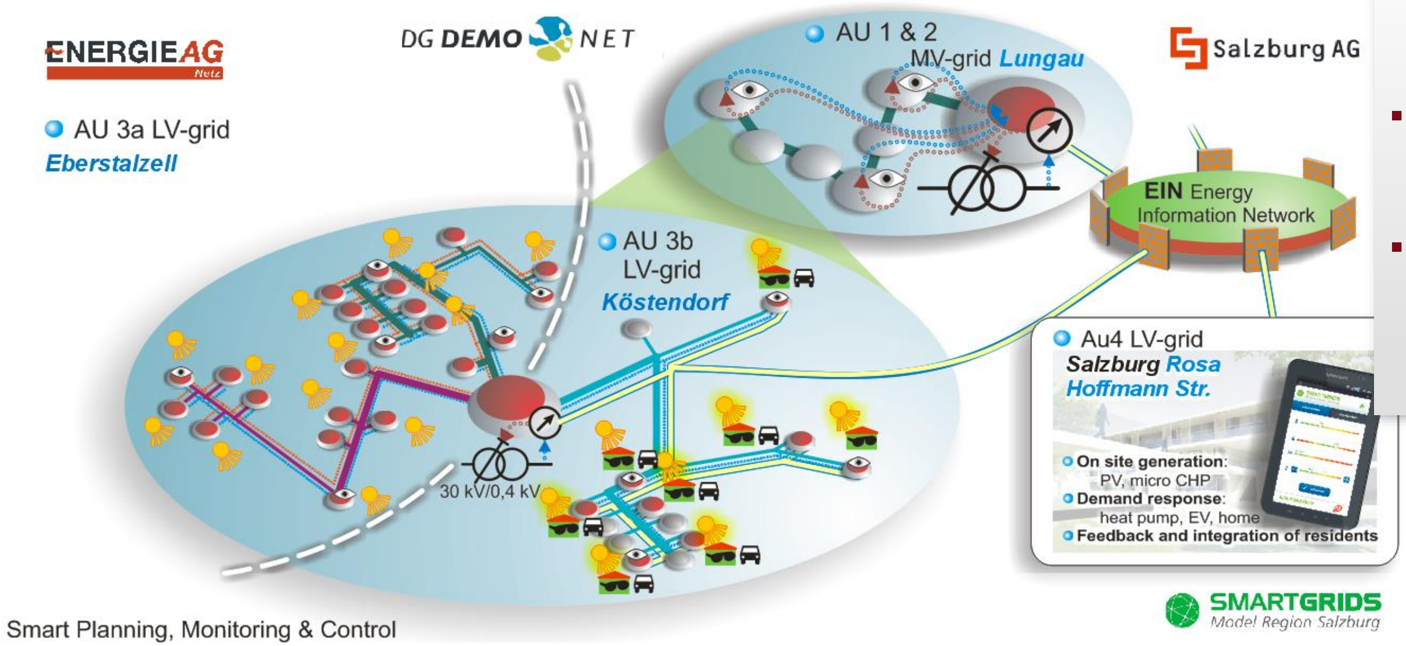
- Interconnection requirement TOR D4 revised 02/2016
  - Treshold level for single phase interconnetion reduced
  - Introduction of voltage control: Q(U), P(U)
  - Idea: increased hosting capacity by local measures on the generator side -> target ~+50%
  - Consideration of energy storage: Same requirements as for DG
  - Definition of „micro generators“ <0,6 kW per installation with fit-and-inform approach

- Green Energy Act
  - Under revision

- ELWOG:
  - solutions for use of PV in multi-family homes under implementation

Example 2: Voltage Control in MV and LV networks

Project Chain DG DemoNet



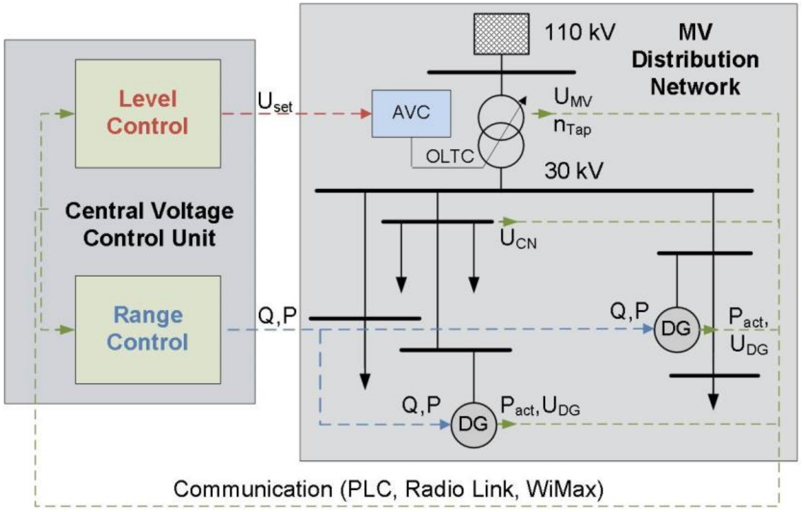
Highlights

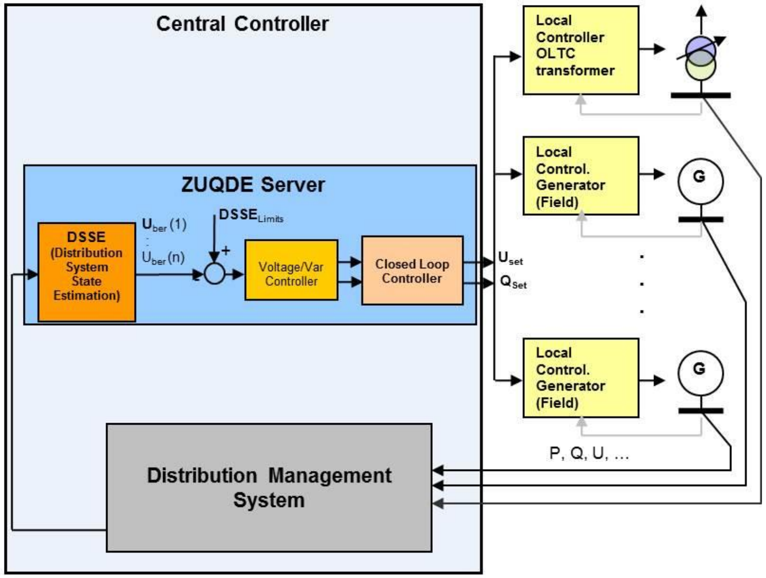
- Increasing the DG hosting capacity of MV and LV networks
- Development of different voltage control concepts
- Evaluation and validation in individual field tests

DG DEMO NETZ KONZEPT · BAVIS · EEGI · DG DEMO NETZ VALIDIERUNG · DG DEMO NET SMART LV GRID

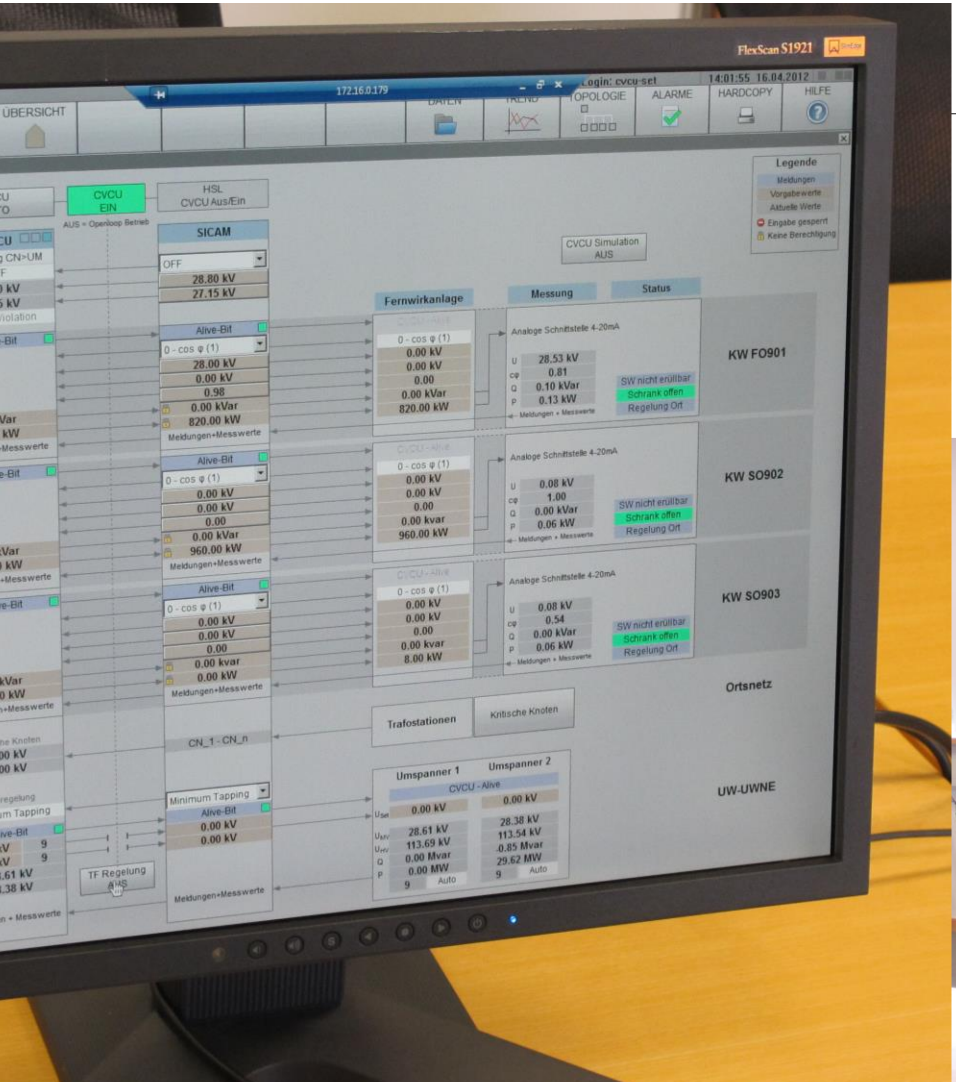
Technologies MV Network

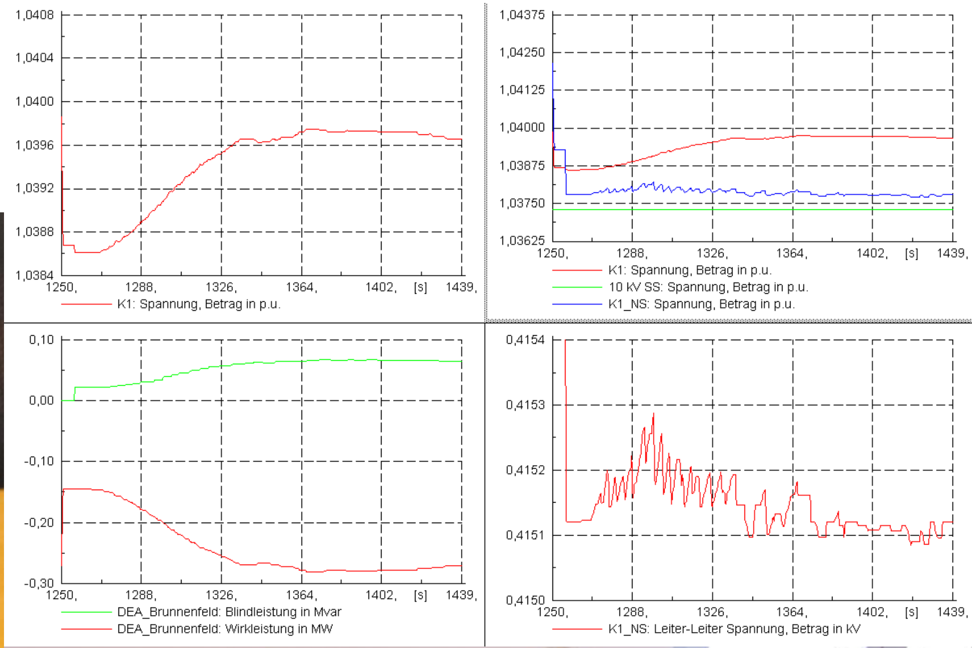
- Two approaches
  - stand-alone solution integrated at substation level (DG DemoNet approach) based on measurements in the grid
  - a solution integrated in a distribution management system based on state estimation (ZUQDE approach)





Pilot Operation in Vorarlberg





Technologies LV Network

- Different controller steps
  1. The OLTC in the secondary substation, as well as the other components within the test area, use their integrated controls and characteristics without communicating with each other (**local control**).
  2. The OLTC receives measurement data from preselected points in the grid so that it can change the tap position to an ideal level for the whole grid (**distributed control**).
  3. In addition to approach 2, all distributed devices (e.g., PV inverters and electric vehicle charging stations) receive the same set points and characteristics (e.g., depending on reactive power control and voltage electric vehicle charging), which are optimized for the current status of the grid (**coordinated control**).

Technologies LV Network –Field Test Areas

Installation of a high penetration of PV and e-mobility

Eberstalzell, Upper Austria

Köstendorf, Salzburg

Prendt, Upper Austria

DG DEMO NET
SMART LV GRID

Results 1/2

- The ZUQDE system based on state estimation (DSSE) and Volt/Var control (VVC) fulfilled the defined functionalities for supporting network operation in terms of voltage band management
- The DG DemoNet control functions can be expected to become a powerful and flexible tool for DSOs to economically integrate additional DGs in grids that recently were reinforced (up to 100% DG share possible with up to 85% cost reduction compared to grid reinforcement).
- Implementation of voltage control concepts in LV and MV networks can increase the hosting capacity significantly
- All smart grid applications developed and tested within the individual projects are seen as part of an overall smart grid approach, which should enable advanced services.

Results 2/2

- Intelligent planning (e.g. balancing of PV in LV feeders) and actual knowledge about utilization of voltage band increases LV hosting capacity significantly
- Highest increase of LV hosting capacity through gaining reserves from MV network via OLTC secondary substation and metering system
- Volt/Var control has limitation when unbalances in LV feeders occur and also in cable networks
- Active power curtailment is more efficient (from a technical point of view)

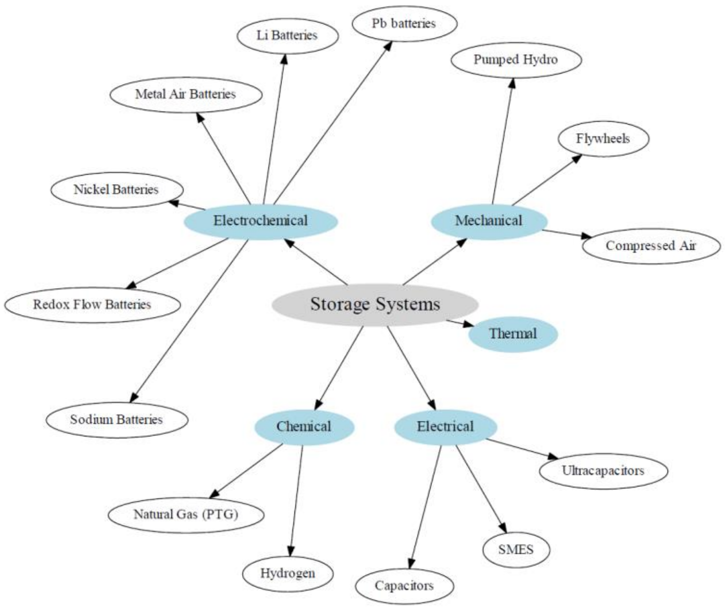
Next Steps

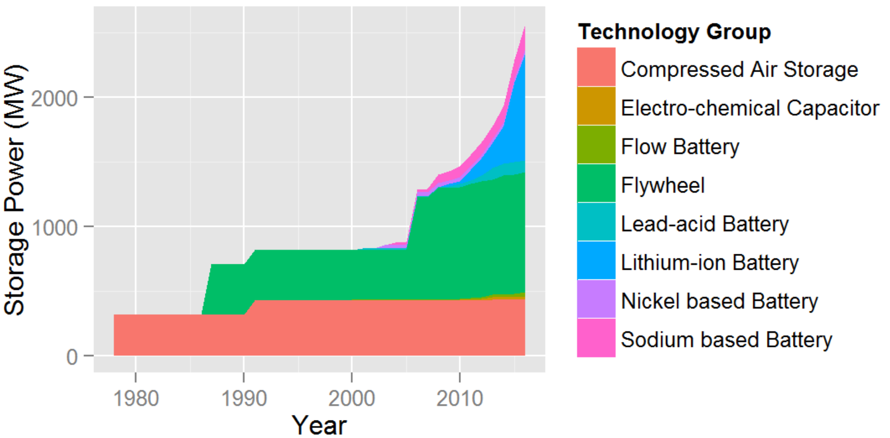
- ZUQDE approach already commercially available
- DG DemoNet control is going to be commercialized within an industry cooperation
- Based on the experiences in LV and MV networks, the next step will be to investigate, further develop, and demonstrate the interaction of all the controls in high voltage, MV, and LV levels and include them in the operational network management (for example EraNet Smart Grid+ Project DeCAS).
- Investigation of the replicability and scalability of the developed solution in Austria.

Example 3: Storage Integration

Electricity Storage Systems

- Storage is seen as a possible key component for the transformation of the energy system
- Multiple use cases for different stakeholders along the energy supply chain
- Huge variety of storage technologies already available
- Progress in the development of Lithium based systems in the recent years
- Open questions concerning both technical and regulatory aspects



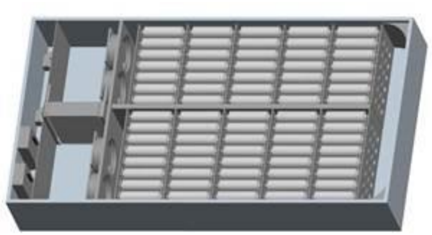


Electricity Storage Systems – Components & Services

Battery

Battery-Management-Systems

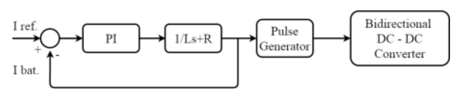
Cells/Modules/Packs



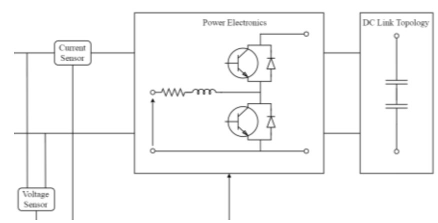
Power System Integration

Power Conversion

Low Level Control

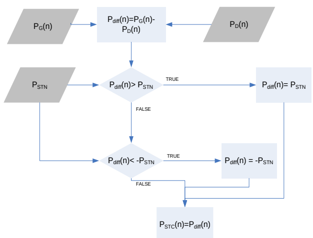


Power Electronics

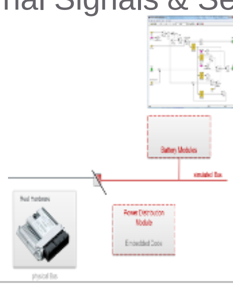


ICT & Control

Control Algorithms



External Signals & Sensors



leafs

Integration of Loads and Electric Storage Systems into Advanced Flexibility Schemes for LV Networks

- **Coordinated flexibility provision** considering all relevant stakeholders
- Development of a **system architecture** for describing the requirements for flexibility provision for relevant components
- Development of **control infrastructure**, interfaces and functions for flexibility provision with distributed and central storage systems as well as home-automation systems
- **Holistic assessment** concering technical, economic, social and regulatory aspects

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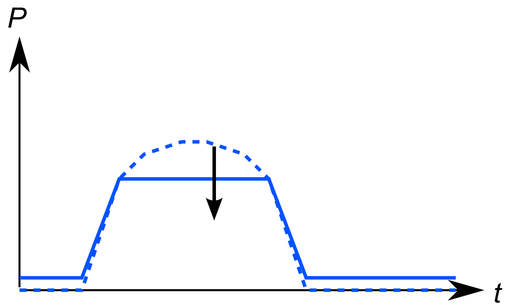
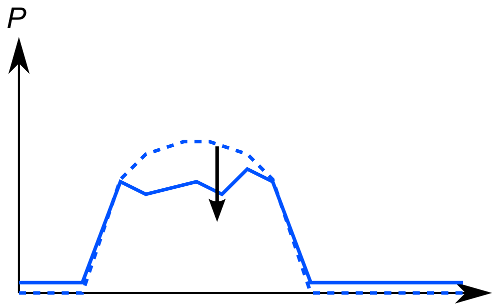
Coordinated use of Flexibility

Level 1



Autonomous optimization

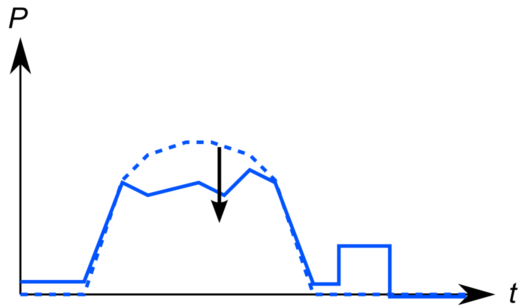
Level 2



Autonomous optimization

Integration in grid control

Level 3



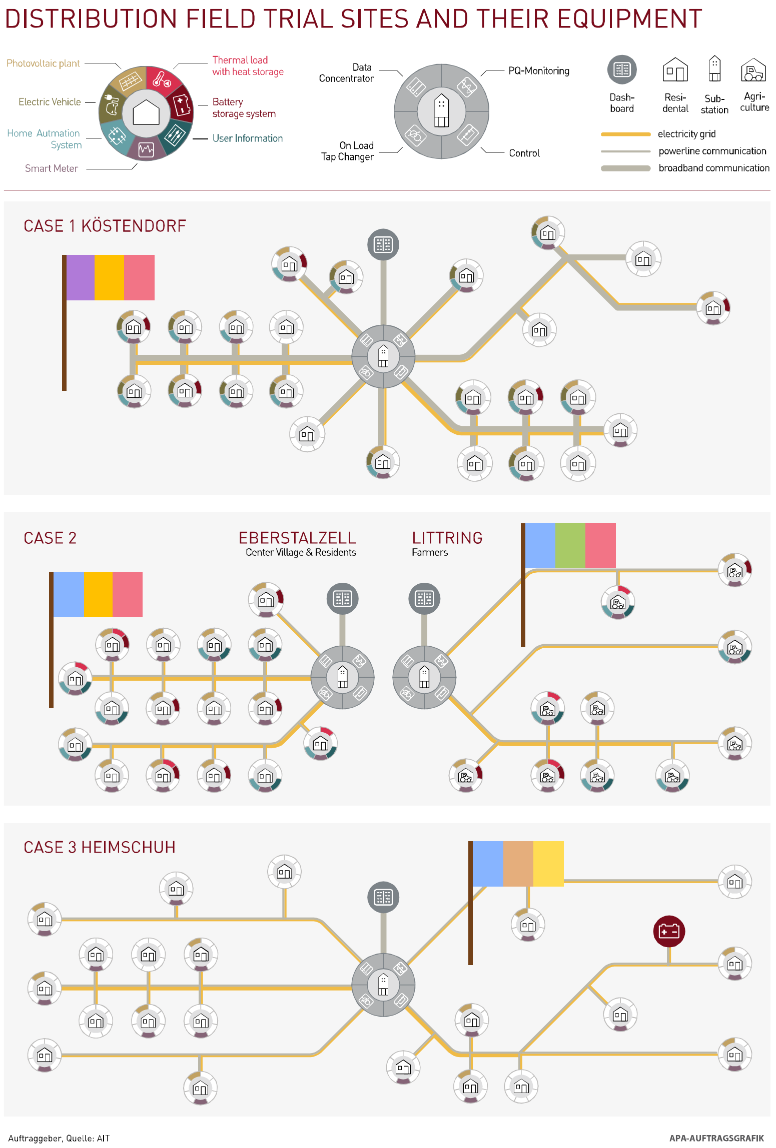
Autonomous optimization

Integration in grid control

Market participation

Field Trials

- **Proof of concept**
  - Real world applicability for the developed provision scheme is shown
  - Existing infrastructure and control approaches are reused and extended and costs reduced
- **Diversified Use Cases**
  - Components: photovoltaic inverter, storage, electric vehicles, home automation, etc.
  - Communication: narrowband, broadband
  - Grid topologies: village, rural, mixed
  - Control approach: direct, indirect, monetary motivation
  - Installation: central storage, distributed storage
- **Customer Integration**
  - Assess willingness of participation in flexibility provision
  - Field trials including new motivation schemes



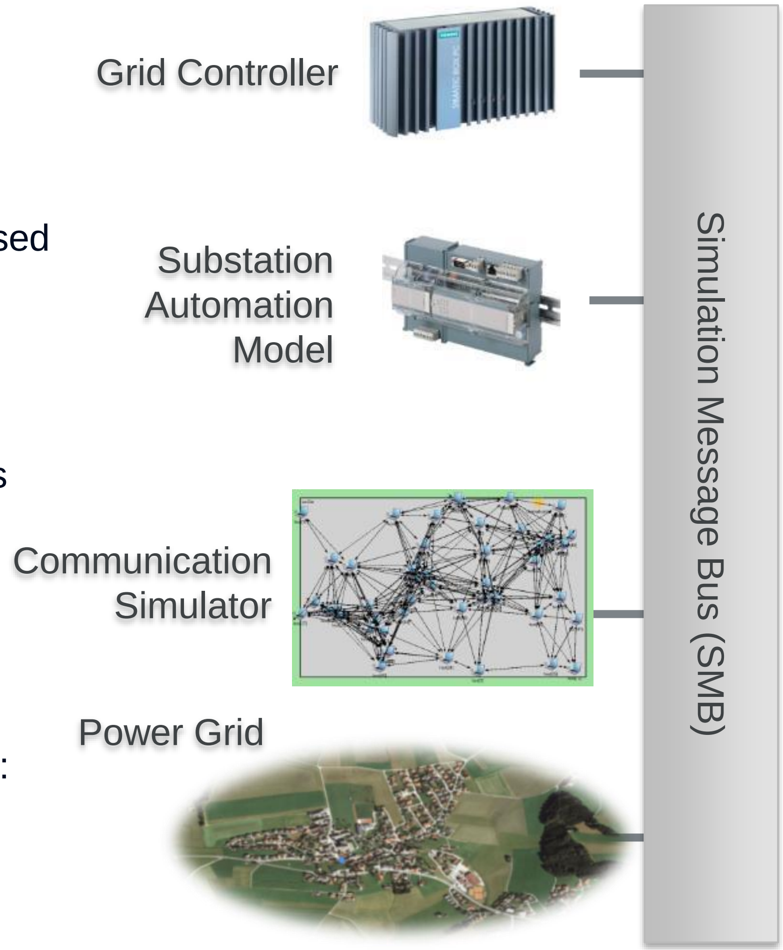
FACDS - Flexible AC Distribution Systems

- Improving power quality through the implementation of FACTS functionalities in storage systems at secondary substation level
- Development of control algorithms for storage inverters in order to provide enhanced ancillary services (e.g. phase balancing)
- Validation in field test in Wien-Aspern with a 100kW/100kWh storage system

Development and validation approaches

Simulation based development approach

- **Component simulation**
  - Design and development of components and control approaches
  - Model validation and model configuration based on laboratory tests
- **Hardware in the loop Simulation**
  - Development of power electronic components
  - Flexible development environment for the development of control approaches
- **Power system simulations**
  - Large scale analysis of new approaches (e.g.: voltage control)
  - Analysing roll-out scenarios



"Case Study" → "big picture" for smart grids solutions

IGREENGrid

Smart grids solutions from pilot projects

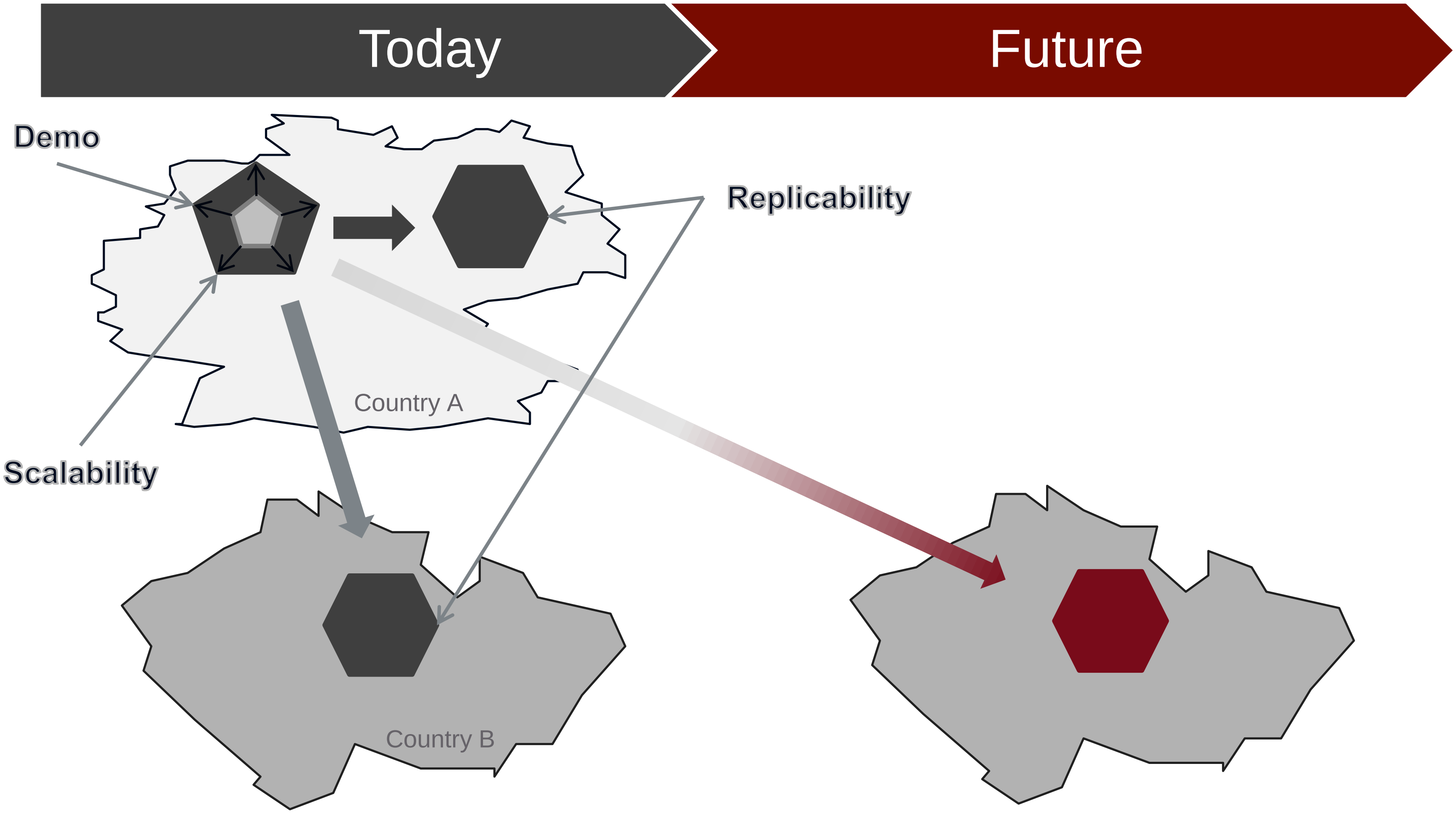
DRES integration

Hosting capacity enhancement

Scalability and replicability

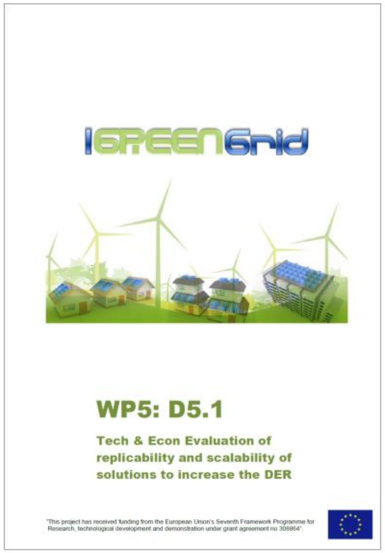
IBERDROLA
gasNatural
enel
HEDNO
erdf L'ÉLECTRICITÉ EN RÉSEAU
RWE The energy to lead
SALZBURGNETZ Ein Unternehmen der Salzburg AG
NETZOÖ Ein Unternehmen der Energie AG

Scalability and replicability analysis - concept



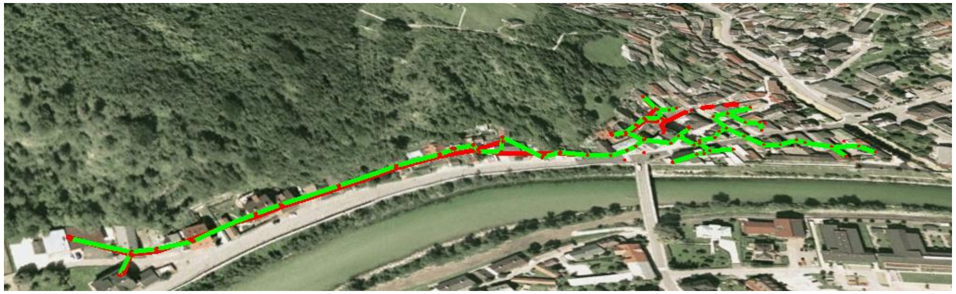
Scalability and replicability of SG solutions – Conclusion

- Quantitative deployment potential of smart grids solutions 37.000 LV feeders:
  - Where (which feeders)?
  - How much (benefit)?
- Feeder classification (voltage/loading-constrained): promising results
- Novel methods and tools for large scale studies available
- More about IGREENGrid:
  - *www.igreengrid-fp7.eu*
  - IGREENGrid @ *Smart Grids Week* 9-13 May 2016 (Linz)
  - CIRED, IEEE ISGT, IEEE TPS, Book chapter

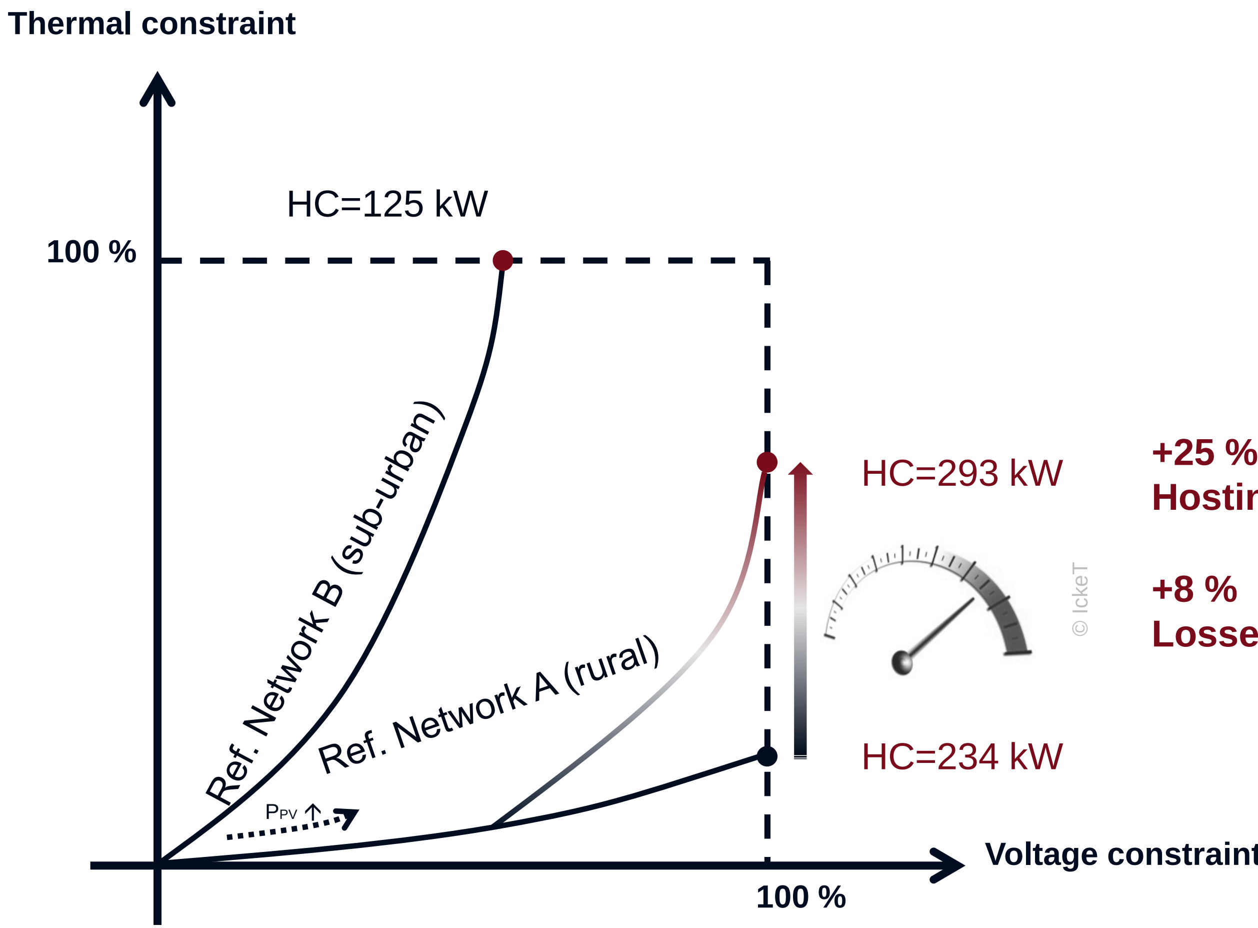


Statistical analysis of LV feeders

- ~37.000 LV feeders
- Parameters (>80)
  - ElDist, GeoDist
  - Impedance, R/X
  - Equivalent sum impedance
  - Number of nodes, loads, lines
  - Average Number and Distance to Neighbours
  - Mesh factor
  - …
- Results
  - Hosting capacity
    - DRES scenarios: uniform / end of feeder / weighted
    - Controls: without / cosφ(P) / Q(U) / VRDT (voltage regulated distribution transformers)



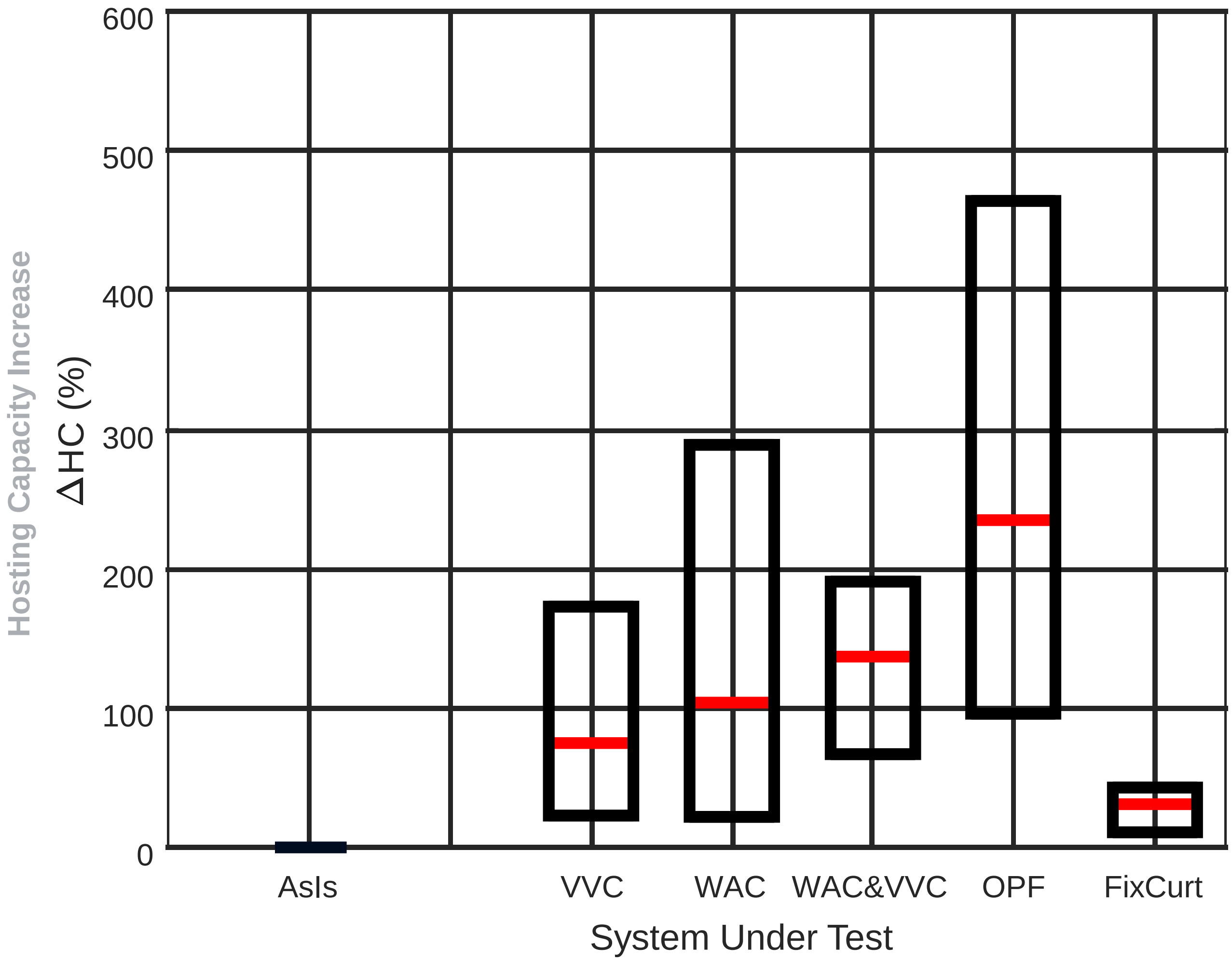
Increase of the hosting capacity: textbook illustration



+25 %
Hosting capacity

+8 %
Losses

Example: Hosting Capacity with different solutions



VVC – Volt Var Control – Reactive Power Control at Photovoltaic inverters

WAC – Wide Area Control – Control with adjustable Transformer based on remote measurements

OPF – Optimal Power Flow – System optimisation calculated in central management system

FixCurt – Fix curtailment of renewable infeed, e.g. 75% of rated power

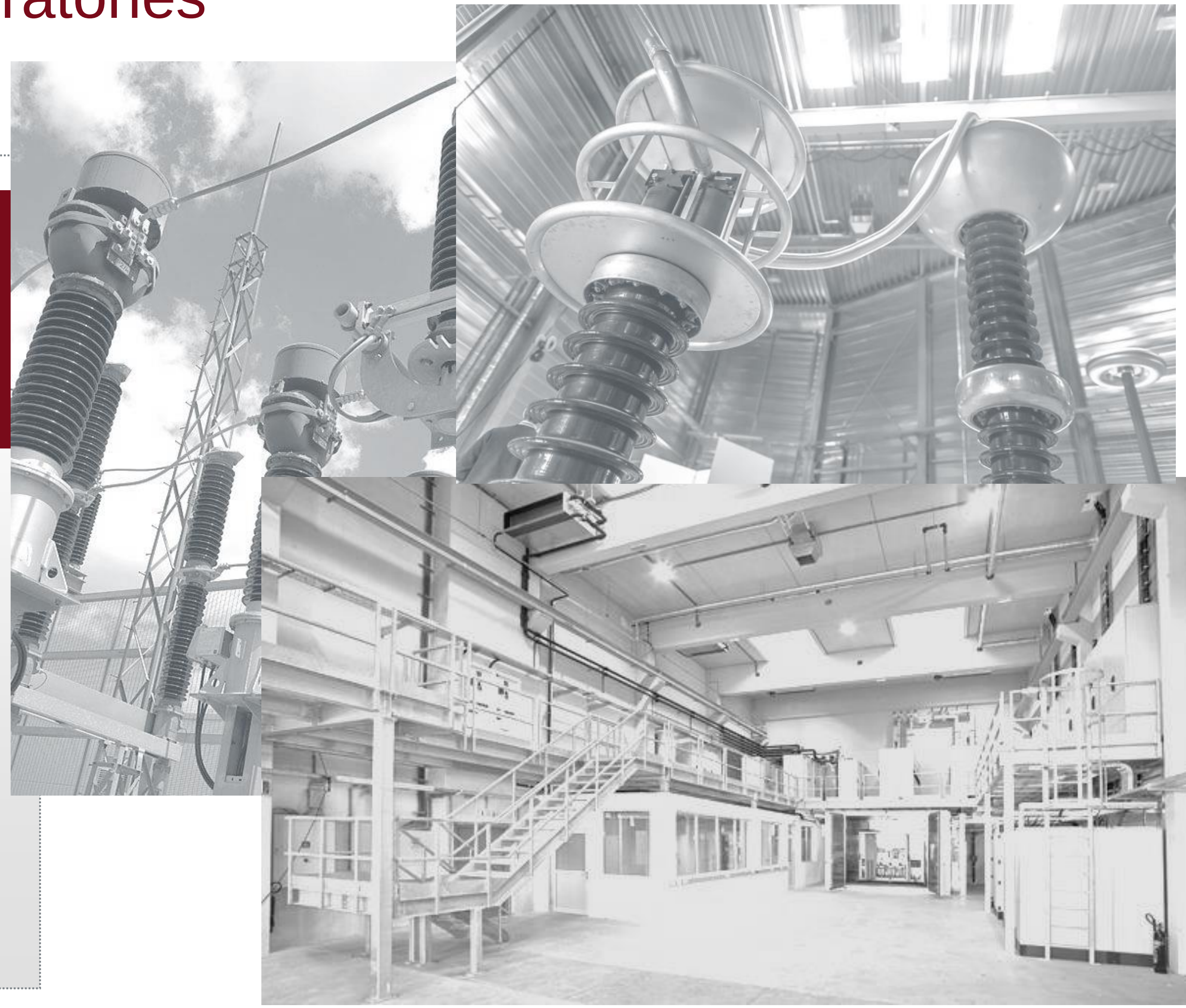
Laboratory based development appraoches

- **Components analysis and development**
  - Characterisation of components concerning efficiency, grid-compliance, etc.
  - Development of interfaces and functions
- **System integration analysis**
  - Component interaction and communications
  - Functional test of the entire system with reduced effort
  - Grid integration aspects and system behavior
- **Analysing non-normal situations**
  - Analysing effects which are difficult to reproduce in the field
  - Analysing voltage deviations, frequency deviations, power outage, loss of communications, etc.

AIT Energy – Laboratories

Smart Grids

- High voltage
- High power
- SmartEST (Smart Grids)
- Power electronics



High voltage laboratory

Testing and optimization of components and systems

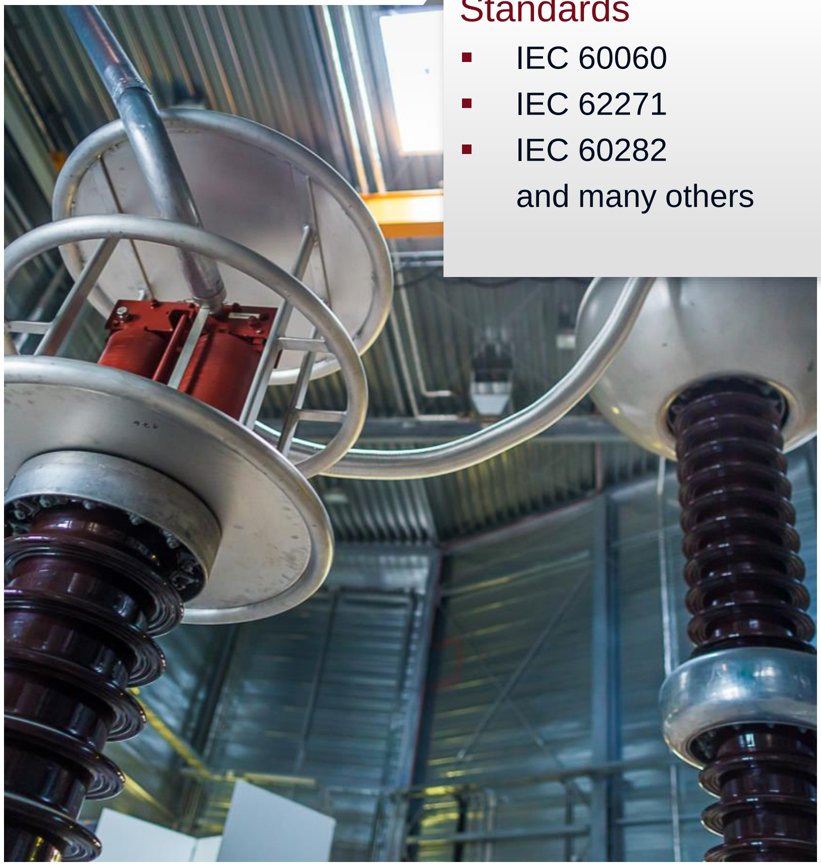
- LV and HV switchgear and controlgear
- LV and HV-fuses
- Transformers and transformer stations

Accredited as CB Testing Lab

- ISO/IEC 17025
- OVE (NBC)
- ISO 9001 Reg. No. CH-12769

Limits and performance data

High voltage	up to 600 kV	AC	max. 1.0 A
High voltage mobile	up to 250 kV	AC	max. 1.5 A
Surge voltage	up to 1200 kV	LI	



Standards

- IEC 60060
- IEC 62271
- IEC 60282

and many others

High power laboratory

Testing and optimization of components and systems

- Different switch fuse combinations
- LV and HV switchgear and controlgear
- Measurement transformers
- HV cables and accessories

Accredited as CB Testing Lab

- ISO/IEC 17025
- OVE (NBC)
- ISO 9001 Reg. No. CH-12769

Limits and performance data

High current AC	0.1 - 40 kV	up to 120 MVA	max.150 kA
High current DC	0.1 - 1 kV 0.1 – 1.5 kV	up to 30 MW	max. 30 kA max. 10 kA

Standards

- IEC 60947
- IEC 60898
- IEC 60269
- IEC 61439
- IEC 61869

and many others

AIT SmartEST laboratory

Research, development and testing of key components for future power systems

- Large-scale advanced, power converters
- Grid connected energy storage systems
- System components for grid-connected, standalone, and microgrid application
- Smart grid components, including smart substations, intelligent DC and AC systems

Test and research infrastructure

- 3 independent test grids up to 1 MVA, 270 - 480 V, variable voltage and frequency
- 1 MW/MVAr RLC resonance circuit
- Facilities for LVRT (low voltage ride-through)
- Advanced hardware-in-the-loop equipment

Environmental simulation

- Test chamber for performance and lifetime testing Temperature range: -40ºC to +120ºC, 98% humidity
- Full power operation of equipment under test

Standards

- IEC 62116/61727
- BDEW
- FGW TR3
- VDE AR-N-4105
- EN/TS 50549
- EN 60068 series

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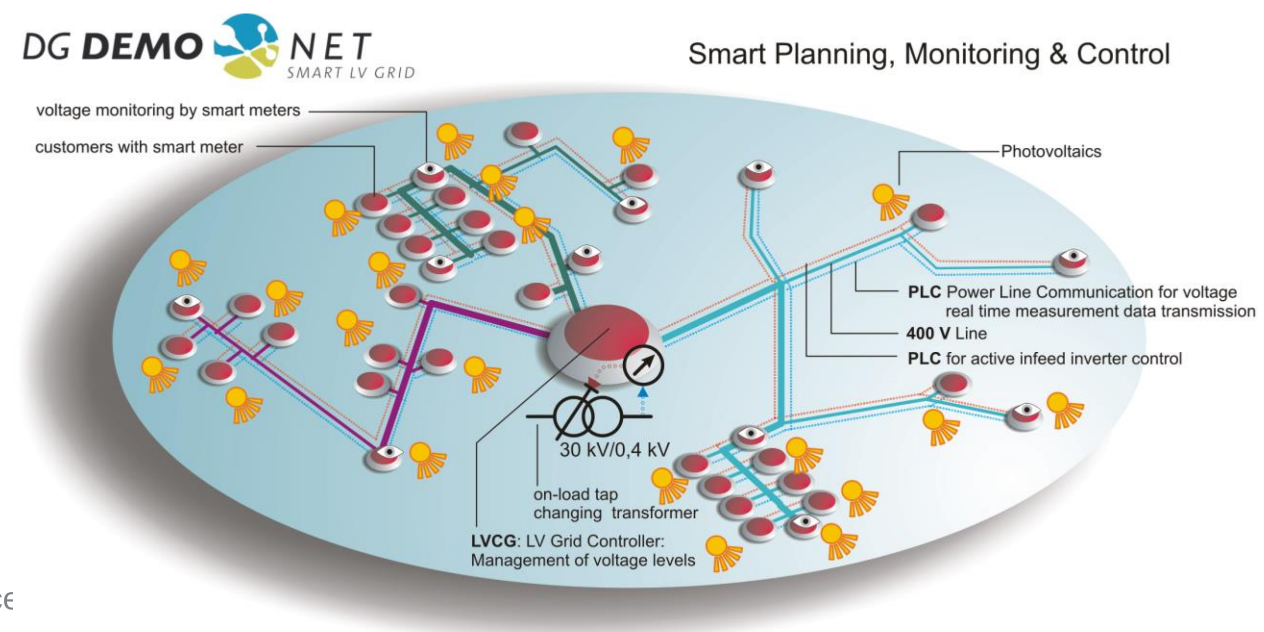
Backup – Facts and Figures LV Field Tests

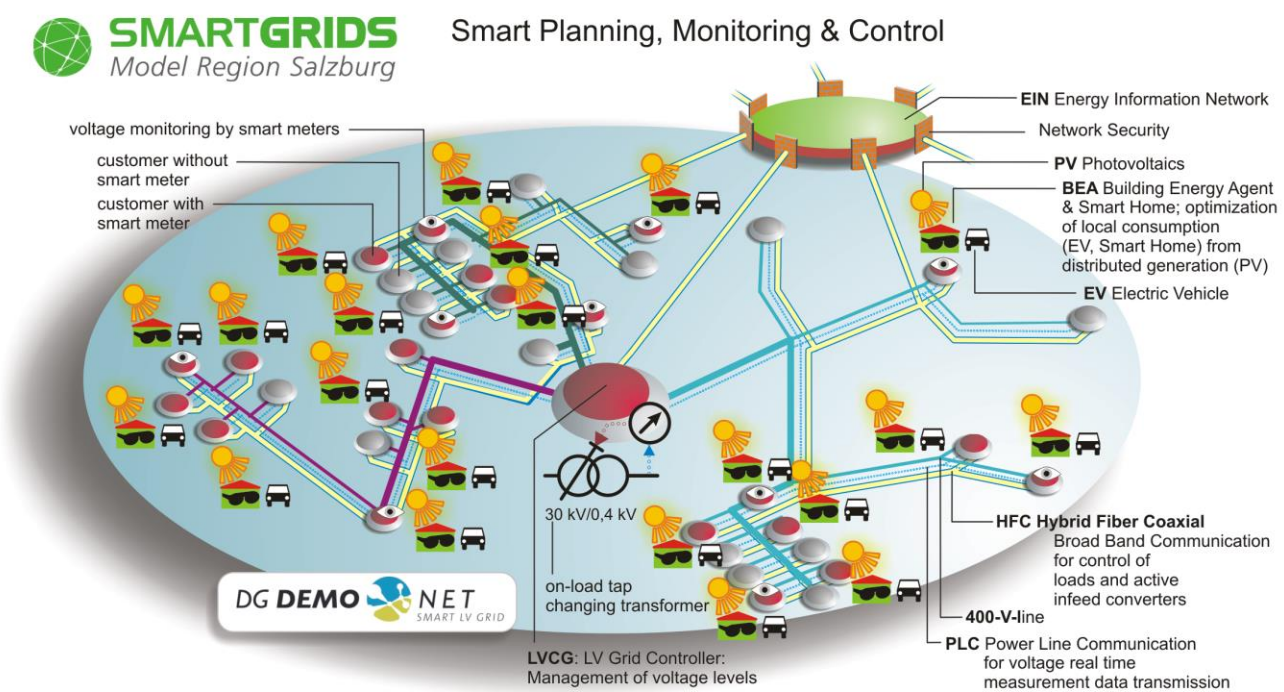
Facts and Figures

- Use Case high penetration PV
- Eberstalzell (Energie AG Netz GmbH)
  - 30/0,4 kV – 630 kVA Transformer
  - *11 branches up to 600m*
  - 173 customers - 1,3 GWh/a 450 kW maximum load
  - 60 PV-Systems roof top 330kWp
- Littring (Energie AG Netz GmbH)
  - 30/0,4 kV – 250 kVA Transformer
  - *5 branches up to 1 km*
  - 54 Buildings/Customers - 0,35 GWh/a 120 kW maximum load
  - 15 PV-Systems roof top 140 kWp



Facts and Figures

- Use Case High penetration PV and e-Mobility
- Köstendorf (Salzburg Netz GmbH)
  - 30/0,4 kV - 250 kVA Transformer, 6 branches up to 1000 m
  - 95 buildings / 127 customers - 0,6 GWh/a 210 kW maximum load
  - 40 PV-Systems roof top 180 kWp, 37 e-cars
  - Building automation for demand side management



Facts and figures

- Use Case probabilistic network interconnection
- Prendt (Linz Stromnetz)
  - Feeder Prendt 1, 14,54 kWp existing PV, 29,13 kWp new installations
  - Feeder Prendt 2, 11,34 kWp existing PV, 97,22 kWp new installations
  - Total 142 kWP